

BLAST – The Balloon-borne Large Aperture Submillimeter Telescope

Mark Devlin^{1*}, Peter Ade², Jamie Bock³, Simon Dicker¹, Matt Griffin², Josh Gundersen⁵, Mark Halpern⁶, Peter Hargrave², David Hughes⁷, Jeff Klein¹, Philip Maukopf², Barth Netterfield⁸, Luca Olmi⁹, Douglas Scott⁶, Greg Tucker¹⁰

¹ University of Pennsylvania, Philadelphia, PA 19104, USA

² Cardiff University, Cardiff, UK

³ Jet Propulsion Laboratory, Pasadena, CA, USA

⁵ University of Miami, Coral Gables, FL, USA

⁶ University of British Columbia, Vancouver, BC, CA

⁷ INAOE, Puebla, MX

⁸ University of Toronto, Toronto, ON, Canada

⁹ University of Puerto Rico, Rio Piedras, Puerto Rico

¹⁰ Brown University, Providence, RI, USA

ABSTRACT

BLAST is the Balloon-borne Large-Aperture Sub-millimeter Telescope. It will fly from a Long Duration Balloon (LDB) platform from Antarctica. The telescope design incorporates a 2 m primary mirror with large-format bolometer arrays operating at 250, 350 and 500 microns.

By providing the first sensitive large-area (10 sq. deg.) sub-mm surveys at these wavelengths, BLAST will address some of the most important galactic and cosmological questions regarding the formation and evolution of stars, galaxies and clusters. Galactic and extragalactic BLAST surveys will: (i) identify large numbers of high-redshift galaxies; (ii) measure photometric redshifts, rest-frame FIR luminosities and star formation rates thereby constraining the evolutionary history of the galaxies that produce the FIR and sub-mm background; (iii) measure cold pre-stellar sources associated with the earliest stages of star and planet formation; (iv) make high-resolution maps of diffuse galactic emission over a wide range of galactic latitudes. In addition to achieving the above scientific goals, the exciting legacy of the BLAST LDB experiment will be a catalogue of 3000-5000 extragalactic sub-mm sources and a 100 sq. deg. sub-mm galactic plane survey. Multi-frequency follow-up observations from SIRTF, ASTRO-F, and Herschel, together with spectroscopic observations and sub-arcsecond imaging from ALMA are essential to understand the physical nature of the BLAST sources.

THE BLAST INSTRUMENT AND SCIENCE GOALS

The primary advantage of BLAST over existing and planned sub-mm bolometer arrays such as SCUBA (Holland, Robson et al. 1999) on the JCMT, SHARC (Hunter, Benford et al. 1996) on the CSO (including their respective upgrades) is its greatly enhanced sensitivity at wavelengths $<500 \mu\text{m}$ due to the dramatically increased atmospheric transmission at balloon altitudes. BLAST complements the Herschel satellite (formerly known as FIRST) by testing identical detectors and filters planned for the SPIRE instrument.

BLAST will be the first long duration balloon-borne telescope to take advantage of the bolometric focal-plane arrays being developed for Herschel. A LDB flight from Antarctica, providing the first surveys at 250, 350 and $500 \mu\text{m}$, will significantly extend the wavelength range, sensitivity, and area of existing ground-based extragalactic and galactic surveys. The instrument parameters are given in Table 1. BLAST will conduct unique galactic and

* Sloan Fellow

extragalactic sub-mm surveys with high spatial resolution and sensitivity. Compared to the pioneering flights of PRONAOS (Lamarre, Giard et al. 1998), BLAST will have an advantage of >100 times the mapping speed. The scientific motivations for BLAST are similar to those of Herschel but are achievable within 2 to 4 years with a series of LDB flights. Additional information on BLAST can be found in Scott et al. (2001) and Hughes et al. (2001).

Using these unique BLAST surveys we expect to achieve the following science goals:

- Conduct a complementary series of wide (shallow) and narrow (confusion-limited) extragalactic 250—500 μm surveys, identifying the galaxy populations responsible for producing the far-IR and sub-mm backgrounds. BLAST will determine the amplitude of clustering of sub-mm galaxies on scales of 0.1—10 degrees.
- Measure the 250—500 μm spectral energy distributions (SEDs) and colors, from which one can derive rest-frame luminosities and star formation rates (SFRs) for sub-mm selected galaxies.
- Measure the sub-mm source-counts and place the strongest constraints to date on evolutionary models and the global star formation history of starburst galaxies at high- z (see Figure 2).
- Conduct Galactic surveys of the diffuse interstellar emission, molecular clouds, and identify dense, cold pre-stellar (Class 0) cores associated with the earliest stages of star formation.
- Observe solar system objects including the Kuiper-belt objects, planets, and large asteroids.

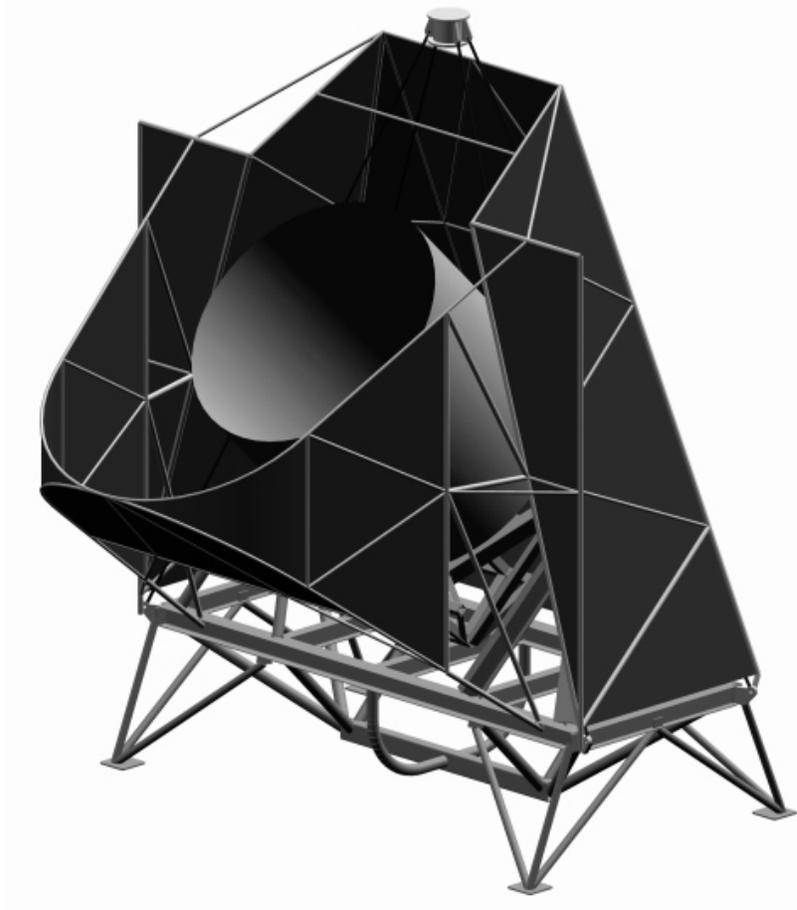


Figure 1 The BLAST Gondola

EXTRAGALACTIC SURVEYS

Observations at sub-mm wavelengths of starburst galaxies in the high- z universe have a particular advantage compared to observations in the optical and FIR because a strong negative k -correction enhances the observed sub-mm fluxes. By early 2002, SCUBA and the millimeter camera MAMBO (operating on the IRAM 30 m) will have com-

Table 1 BLAST Telescope Parameters

Telescope			
Temperature	200 K		
Throughput for each pixel	λ^2		
Bolometers			
Central Wavelengths (microns)	250	350	500
Number of Pixels	149	88	43
Beam FWHM (arcseconds)	30	41	59
Field of View for Each Array (arcmin)	6.5×14		
Overall Instrument Transmission	30%		
Filter Widths	$\sim 30\%$		
Observing Efficiency	90%		

Table 2 BLAST sensitivities. Sensitivities for SCUBA and SOFIA are given for comparison.

	250 μm	350 μm	500 μm
Background power [pW]	25.6	18.3	13.5
Background limited NEP [$\text{W Hz}^{-0.5} \times 10^{-17}$]	20	14	10
NEFD [$\text{mJy } \sqrt{\text{sec}}$]	236	241	239
ΔS (1σ , 1hr) (1 sq. deg.) [mJy]	38	36	36
ΔS (1σ , 6hr) (1 sq. deg.) [mJy]	15.5	14.7	14.6
Comparison with SCUBA (average NEFD) [mJy $\sqrt{\text{sec}}$]	-	1100	1000
Comparison with SOFIA (calculated NEFD) [mJy $\sqrt{\text{sec}}$]	550		

pleted their first series of extragalactic sub-mm and mm (850 μm — 1.3 mm) surveys. Although covering areas ranging from 0.002 to 0.2 deg^2 (Smail, Ivison et al. 1997; Hughes, Serjeant et al. 1998; Lilly, Eales et al. 1999; Carilli, Owen et al. 2001), these ground-based surveys are hundreds of times smaller than the proposed BLAST surveys (see Table 2).

The following results from the first SCUBA (850 μm) and MAMBO (1.25 mm) surveys have made a significant impact on several cosmological questions, while at the same time demonstrating the necessity for larger area and shorter-wavelength (250—500 μm) sub-mm observations:

- 30—50% of the sub-mm/FIR background detected by COBE has been resolved into individual sub-mm galaxies. The existing confusion-limited surveys are within a factor of a few in sensitivity of resolving the entire sub-mm/FIR background.

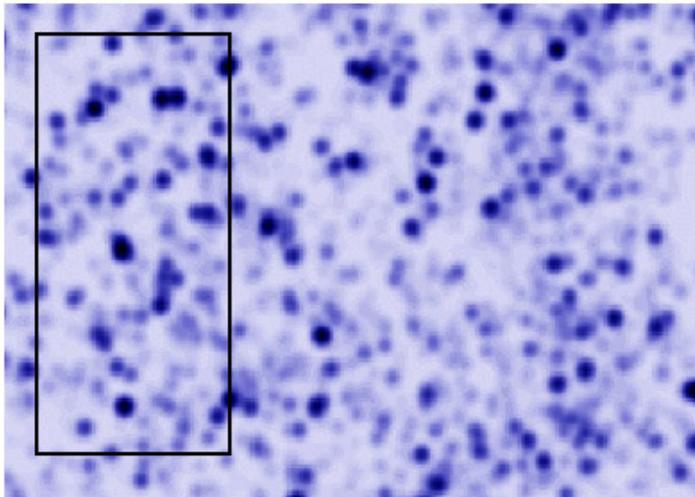


Figure 2 A simulated confusion-limited BLAST 250 μ m survey with a FWHM resolution of 30' and a 1σ sensitivity of 7 mJy. The assumptions for the evolution and the clustering of submm galaxies are described in Hughes & Gaztanaga 2000. The simulation area covers 0.1 deg² and is 1/10th the size of our smallest proposed survey. The rectangle represents the field of view of the 250 μ m array.

- The majority of sub-mm sources appear to be associated with $z \gg 1$ Extremely Red Objects (EROs - IR galaxies that are extremely faint or undetected in the optical) and weak radio sources. There is still vigorous debate about the fraction of sources at $z \geq 2$.
- The sub-mm source-counts significantly exceed a no-evolution model and require strong evolution out to $z \sim 1$, but place weak constraints at higher redshifts. The source-counts at bright sub-mm flux densities ($N_{850} > 10$ mJy) show a large scatter (about a factor of 5) between different surveys which may be the result of clustering on the scale of these surveys.
- The sub-mm surveys appear to find ~ 5 times the star formation rate that is observed in optical surveys at $2 < z < 4$; how much of this discrepancy is due to the effects of dust obscuration and incompleteness in the optical is still being investigated (Adelberger and Steidel 2000).

BLAST/SCUBA OBSERVATIONS

A combined wide-area sub-mm survey is planned using SCUBA (at 850 and 450 μ m) and BLAST (at 250, 350 and 500 μ m) to (i) determine the star-formation history of massive, dust-enshrouded galaxies, (ii) identify whether these blank-field sub-mm galaxies are the progenitors of massive elliptical galaxies, and (iii) to provide photometric redshifts with sufficient accuracy to measure the evolution of the spatial clustering of the sub-mm sources. The planned SCUBA+BLAST survey will coordinate observations towards two "cirrus-free" fields covering a total of 0.5 sq. degrees that are accessible from Hawaii and a northern and southern hemisphere LDB flight.

The existing ground-based SCUBA surveys have identified more than 100 blank-field sub-mm sources. Unfortunately, due to the ambiguity in identifying a sub-mm galaxy with its optical counterpart, spectroscopic redshifts exist for only ~ 5 sub-mm sources. This "redshift deadlock" prevents a complete understanding of the nature and evolutionary history of sub-mm galaxies, since without redshifts, it not possible to measure the rest-frame luminosities, or the star-formation history for this population of optically-obscured galaxies.

The SCUBA+BLAST survey is designed to detect > 100-200 galaxies with accurate photometric sub-mm colors between 250 and 850 μm . Monte-Carlo simulations, that take into account the errors in the measurement and calibration, and the errors in the evolutionary models and spectral energy distributions of galaxies that fit the observed sub-mm number-counts, demonstrate that photometric redshifts with uncertainties of $z = \pm 0.4$ can be obtained for galaxies over the redshift range $0 < z < 6$ (Hughes et al. 2001). Future millimeter-wavelength spectroscopic follow-up observations with the 100-m GBT and 50-m LMT will calibrate the accuracy this method. The cumulative redshift distribution for the population of galaxies detected in the SCUBA+BLAST survey, with FIR luminosities $> 3 \times 10^{12} L_{\text{solar}}$, will provide the necessary information for a robust measurement of the SFR density between $0 < z < 6$ with an accuracy of $\pm 20\%$. Furthermore, the combined SCUBA+BLAST survey will provide photometric redshifts with sufficient accuracy to remove any projection effects in the measured clustering signal, which itself is also a powerful test of whether the sub-mm galaxies are strongly-biased and trace high-mass peaks in the initial density fluctuations.

SCHEDULE

The BLAST instrument will have its first North American flight in the spring of 2003 from Ft. Sumner, New Mexico. The primary purpose of the first flight is to test the integrated system and qualify for the LDB flight from Antarctica in December of 2003. The test flight will incorporate only the 500 micron array. The 250 and 350 micron arrays will be installed in the summer of 2003 in preparation for the LDB flight.

ACKNOWLEDGMENTS

BLAST is supported by NASA (NRA-99-01-SPA-015) and the NASA Rhode Island Space Grant.

REFERENCES

- Adelberger, K. and C. C. Steidel (2000). "Multiwavelength Observations of Dusty Star Formation at Low and High Redshift." *ApJ* **544**: 218.
- Carilli, C. L., F. Owen, M. Yun, F. Bertoldi, A. Bertarini, K. M. Menten, E. Kreysa and R. Zylka (2001). *Deep Millimetre Surveys - Implications for Galaxy Formation and Evolution*, World Scientific.
- Holland, W. S., E. I. Robson, W. K. Gear, C. R. Cunningham, J. F. Lighfoot, T. Jenness, R. J. Ivison, J. A. Stevens, P. A. R. Ade, M. J. Griffin, W. D. Duncan, J. A. Murphy and D. A. Naylor (1999). "SCUBA: a common-user submillimetre camera operating on the James Clerk Maxwell Telescope." *MNRAS* **303**: 659.
- Hughes, D., S. Serjeant, J. Dunlop, M. Rowan-Robinson, A. Blain, R. G. Mann, R. Ivison, J. Peacock, A. Efstathiou, W. Gear, S. Oliver, A. Lawrence, M. Longair, P. Goldschmidt and T. Jenness (1998). "High-redshift star formation in the Hubble Deep Field revealed by a submillimetre wavelength survey." *Nature* **394**: 241.
- Hughes, D.H., Aretxaga, I., Chapin, E.L., Gaztanaga, E., Dunlop, J.S., Devlin, M.J., Halpern, M., Gundersen, J., Klein, J., Netterfield, C.B., Olmi, L., Scott, D., Tucker, G., (2000), "Breaking the Redshift Deadlock - I: Constraining the star formation history of galaxies with sub-millimetre photometric redshifts," astro-ph/0111547 submitted MNRAS.
- Hunter, T. R., D. J. Benford and E. Serabyn (1996). "Optical Design of the Submillimetre High Angular Resolution Camera (SHARC)." *PASP* **108**: 104.
- Lamarre, J. M., M. Giard, Pointecouteau, B. E., J.P., , G. Serra, F. Pajot, F. X. Desert, I. Ristorcelli, J. P. Torre, S. Church, N. Coron, J. L. Puget and J. J. Bock (1998). "First Measurement of the Submillimetre Sunyaev-Zeldovich Effect." *ApJ* **507**: L5.
- Lilly, S., S. Eales, W. K. Gear, F. Hammer, O. Le Fevre, D. Crampton, R. Bond and L. Dunne (1999). "The Canada-United Kingdom Deep Submillimetre Survey. II. First Identifications, Redshifts, and Implications for Galaxy Evolution." *ApJ* **518**: 641.
- Scott, D., Ade, P., Bock, J., deBernardis, P., Devlin, M., Griffin, M., Gundersen, J., Halpern, M., Hughes, D., Klein, J., Masi, S., Maukopf, P., Netterfield, B., Olmi, L., Page, L., Tucker, G., (2000), "The Balloon-Borne

Large Aperture Sub-Millimeter Telescope,” Proc. Symposium ‘The Promise of the Herschel Space Observatory’ 12-15 December 200, Toledo, Spain.
Smail, I., Ivison and A. W. Blain (1997). "A Deep Sub-millimeter Survey of Lensing Clusters: A New Window on Galaxy Formation and Evolution." MNRAS **490**(L5).